AMRL-TR-79-81

SOUND-EVOKED VISUAL FIELD SHIFTS: INTERACTION WITH FIVE CLASSES OF STIMULATION

D. E. PARKER
W. L. GULLEDGE
W. PEREZ
R. POSTON

DEPARTMENT OF PSYCHOLOGY
MIAMI UNIVERSITY
OXFORD, OHIO 45056

JANUARY 1980

AIR FORCE AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from Air Force Aerospace Medical Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies and their contractors registered with Defense Documentation Center should direct requests for copies of this report to:

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314

TECHNICAL REVIEW AND APPROVAL

AMRL-TR-79-81

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

HENNING E. VON GIERKE
Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

AIR FORCE/56780/29 January 1980 — 200

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

12

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 18 AMRL-TR-79-81	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 SOUND-EVOKED VISUAL FIELD SHIFTS: INTERACTION WITH FIVE CLASSES OF STIMULATION		5. TYPE OF REPORT & PERIOD COVERED 9 Final Rep[redacted]t, 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 D. E. Parker, W. L. Gulledge, W. Perez, R. Poston		8. CONTRACT OR GRANT NUMBER(s) 15 F33615-73-C-5029
9. PERFORMING ORGANIZATION NAME AND ADDRESS Miami University Oxford, Ohio 45056		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 16 17 62202F, 7231-03-22
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, OH 45433		12. REPORT DATE 11 Jan[redacted]80 13. NUMBER OF PAGES 44
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 12 44		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Visual field displacements evoked by acoustical transients in human beings have been described previously (AMRL-TR-77-81). The influence of several variables on this phenomenon was examined in five studies. Experiment I investigated the interaction between acoustical stimulation and angular acceleration. The results of this experiment support the view that the acoustical transients activate semicircular canal receptors. The influence of head vibration on acoustical

DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

405 944

Block 20--Continued

transient-evoked visual field displacements was examined in Experiment II. Smaller visual field displacements were reported when head vibration was presented simultaneously with the acoustical stimulation, probably because the head vibration activated the middle ear reflex. No changes in acoustical stimulus-evoked visual field displacements following exposure to a rotating visual field (Experiment III) or as a function of visual target illumination intensity (Experiment IV) were observed. Finally, alcohol ingestion (Experiment V) reduced the magnitudes of the visual field displacement reported by the subjects.

PREFACE

The research described in this report was performed under Contract F 33 615 73 C 5029 between the United States Air Force and Miami University, Oxford, Ohio.

This investigation was conducted in accordance with guidelines established by the Miami University Human Subjects Committee.

We thank our colleagues who have contributed to this effort, particularly H. E. von Gierke and C. S. Harris.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

SECTION I

INTRODUCTION

In previous studies, personnel at Miami University and Wright-Patterson Air Force Base have investigated the effects of pressure transients, infrasound, and intense audiofrequency sound on (a) the response of the ossicular chain, (b) pressure changes in inner ear fluids, (c) the response of the vestibular nerve, (d) head and eye movements, and (e) perceived visual field displacements. Guinea pigs, monkeys, and human subjects have been examined in these investigations (refs 13-20). These studies and others (refs 7-9) suggest that sound and pressure stimuli activate the receptors of the semicircular canals to produce head movements, eye movements, and perceived displacements of the visual field.

In the study on visual field displacements evoked from human beings by acoustical transients (ref 16), we found that approximately one-half of the 133 subjects who were exposed to the acoustical stimuli at 125 dB SPL reported visual field displacements. Stimuli in the 500- to 1000-Hz frequency range at repetition rates of about 1/sec resulted in the largest proportion of responses.

The present series of experiments examined the contribution of other variables to visual field displacements evoked by acoustical transients. The specific variables investigated included angular acceleration (Experiment I), mastoid vibration (Experiment II), prior exposure to a rotating visual field (Experiment III), intensity of target illumination (Experiment IV), and alcohol ingestion (Experiment V).

EXPERIMENT I--ANGULAR ACCELERATION

The results of previous investigations supported the hypothesis that pressure transients (step and ramp functions of pressure change) at the tympanic membrane and intense audiofrequency transients affect the receptors of the semicircular canals. The observations that led to this conclusion included the following: (a) pressure transients evoke nystagmus in guinea pigs and monkeys; (b) intense audiofrequency sound evokes nystagmus in human beings; (c) the nystagmus response is lost in animals following eighth nerve section; (d) vestibular nerve responses can be evoked by pressure transients; (e) nystagmus is retained following damage to the otolith organs by centrifugation; (f) the nystagmus response is lost following damage to the semicircular canals.

Experiment I examined the hypothesis that prior exposure to angular acceleration would alter the reports of visual field displacement evoked by acoustical transients. After a sudden angular deceleration, the cupulae of the semicircular canals in the plane of rotation are initially displaced and then gradually return to their resting position. If, as suggested by previous research, acoustical transients result in cupula displacement, the effects of angular deceleration should interact with the effects of acoustical stimulation. Whether the visual field shift is enhanced or suppressed depends on the direction of the angular acceleration and/or the ear stimulated. Given apparatus constraints, it was more convenient to maintain the direction of angular deceleration constant and to vary the ear which received the acoustical stimuli. The hypothesis was that the magnitude of sound-evoked visual field shifts after angular deceleration would differ for right ear and left ear stimulation.

EXPERIMENT II--HEAD VIBRATION

Lackner and Graybiel (ref 12) recently reported that visual and postural illusions, nystagmus, and motion sickness were produced by head vibration. These effects were obtained by

stimulation at various head loci with the clearest responses associated with stimulation around the ear. They suggest that vibration affects the semicircular canals; however, no explanations are offered for the causative biomechanical processes. We and others (C. S. Harris, personal communication) have attempted to repeat the observations reported by Lackner and Graybiel without success. Although some visual field displacement may be associated with vibration onset, this displacement appears to be related to a "startle" reaction rather than to vestibular stimulation. Visual illusions were not reported by our subjects during or after head vibration.

Perhaps the behavioral techniques that we employed were not sufficiently sensitive to duplicate the results of Lackner and Graybiel. If they are correct in assuming that vibration stimulates the semicircular canals and if we are correct in assuming that intense acoustical transients also stimulate the semicircular canals, then either enhancement or suppression of visual field shifts should be associated with simultaneous presentation of vibration and acoustical transients, depending upon the relationship between the ear stimulated and the vibration. Regardless of the direction of the effect obtained with the right ear, the effect obtained with the left ear should be opposite. Experiment II was designed to evaluate this suggestion.

EXPERIMENT III--PRIOR VISUAL FIELD ROTATION

Several investigators have examined the influence of rotating visual environments on eye movement responses (optomotor responses) (ref 11) as well as on subjective perception (ref 3). The purpose of Experiment III was to determine whether prior exposure to a rotating visual field comprised of alternating black and white stripes would influence the incidence and magnitude of visual field displacements evoked by acoustical transients.

EXPERIMENT IV--TARGET ILLUMINATION

Change in visual responses evoked by vestibular stimulation as a function of the illumination intensity of the visual target has been examined in several laboratories (refs 1, 2, 5, 6). Experiment IV was performed to examine the hypothesis that the magnitude of the visual field shift elicited by intense acoustical transients would be reduced when the target was brightly illuminated. This hypothesis was derived from the observation that nystagmus is suppressed by visual field illumination (ref 6).

EXPERIMENT V--ALCOHOL INGESTION

Numerous investigators have examined the influence of alcohol ingestion on responses evoked by vestibular stimulation (e.g., refs 2, 5, 10, 21). Heifer (ref 10) and Schroeder (ref 21) have reported that alcohol depresses vestibular nystagmus when the observations are obtained in darkness, whereas nystagmus responses are enhanced if the recordings are obtained in light. The former observation has been accounted for by the general depression of vestibular responses produced by alcohol and the latter observation has been related to the depressive action of alcohol on the visual fixation mechanism.

Following the results of Schroeder (ref 21) and previous experiments undertaken at Miami University employing guinea pigs and monkeys (ref 17), it was hypothesized that smaller visual field shifts would be reported by human subjects following ingestion of alcohol. Experiment V was designed to evaluate this hypothesis.

SECTION II

METHOD

A. EXPERIMENT I--ANGULAR ACCELERATION

Two experiments were performed on the interaction between acoustical stimulation and angular acceleration. In Experiment I-A changes in the magnitudes of perceived visual field displacements were examined following angular deceleration at three levels, and in Experiment I-B both magnitude and direction effects were studied.

Experiment I-A

Twelve graduate students were paid to participate in Experiment I-A. These twelve were selected from a larger group of volunteers because they exhibited hearing losses less than 20 dB (500- to 8000-Hz) in an audiometric examination and initially reported visual field displacements upon exposure to the acoustical transients presented during the first part of the experiment. All subjects were given a second audiometric examination after completing the experiment to ensure that no permanent threshold shifts were produced by the sound exposures at any of the audiometric test frequencies. Audiometry was performed with a Grason-Stadler tracking audiometer (model 1703).

Tone bursts (pulses) were formed by passing an oscillator (Hewlett-Packard model 200 CD) signal through an electronic switch (Grason-Stadler model 1287), controlled by two timers (Grason-Stadler model 1216), to an attenuator set (Hewlett-Packard 350D) and a 40-W McIntosh amplifier. The signal from the amplifier activated a TDH 49 earphone which was attached to an MX-41/AR cushion. Sound-level calibrations were made using a General Radio octave-band noise analyser (model 1558BP) and a General Radio coupler (model 1560-P83). Absolute sound-pressure-level calibration was obtained with a General Radio piston

phone (model 1562-A).

The visual target was a black cross formed by a horizontal line and a vertical line (both 7.6 × 7.6 cm) drawn on a piece of white paper (21.6 × 27.9 cm). The target was placed, at approximately eye level, 150 cm directly in front of the seated subject, whose head was positioned in a U-shaped chin rest. A Naren spotlight (model N-103) illuminated the target, and the brightness at the subjects' eye was 100 mL.

Angular acceleration was obtained with a centrifuge. The centrifuge consisted of a 122-cm radius circular platform which was driven through a reduction gear by a 10-horsepower, variable-speed DC motor. A servo regulator maintained the centrifuge rotation rate at the level determined by the experimenter. The subject was restrained in a padded aircraft chair during centrifugation.

After the audiometric examination all of the subjects were shown the basic apparatus and told that the experiment involved exposure to loud sounds and rotation for a brief period. The subjects were then read the following instructions.

> "I would like you to look at the cross on the wall while I present a series of loud beeps through the earphone. I would like to know if you see any changes in the cross while the sound is on. Other subjects have reported a variety of changes; some subjects report no changes at all. I would like to have you tell me about anything that you see."

In the first part of the experiment, the subjects were exposed to six stimulus trains (10 tone bursts in each train) presented to either the left or right ear and following rotation at 30, 60, or 90 deg/sec. Acoustical stimulus characteristics were held constant: frequency--500 Hz, intensity--125 dB SPL,

repetition rate--0.9/sec, duration--100 msec, and onset/offset time--1 msec.

Before the sound presentation, the centrifuge was slowly accelerated until a constant angular velocity of 30, 60, or 90 deg/sec was reached. The angular velocity was maintained for a period of 2 min after which the centrifuge was stopped as rapidly as possible (0.3 sec for 30 deg/sec, 0.85 for 60 deg/sec, and 1.3 for 90 deg/sec). The subject was then oriented toward the target and the earphone was placed over the right or left ear. After the subject's head was in the head holder, a series of 10 tone bursts was presented. A period of 0.7-0.9 sec elapsed between termination of rotation and the start of the tone burst presentation.

A trial consisted of exposure to the series of ten tone bursts to either the right or left ear following rotation at a particular rate. One trial was completed for each of the six experimental conditions (two ears by three rotation rates). The order of trials was counterbalanced and varied across subjects. A 2-min rest interval intervened between trials.

At the end of each trial the subject was asked to report any changes in the target associated with the acoustical stimuli. Only reports of target motion constituted a positive response; other reports (e.g., changes in color, line width, shadowing, and so on) were recorded as negative responses for the purposes of this experiment.

Those subjects who reported target motion on at least one of the six trials during the first part of the experiment proceeded to the second part. In this second part, the subjects were asked to estimate the amount of perceived target motion correlated with each of the six conditions. The subjects were read the following instructions.

"You have reported motion of the cross associated with the beeps. Now I would like you to estimate the amount of motion associated with beeps after rotation at different rates. I will present a series of beeps. Use any number you wish to indicate the amount of motion produced by the beeps. Then I will present another series of beeps after rotation at a different rate. If the amount of motion that you see is twice as large for the second series of beeps as for the first series, use a number twice as large as you used for the first series. If the amount of motion is half as great, use a number half as large. You may use any numbers that you wish--whole numbers, decimals, fractions--to indicate the amount of motion that you see. We ask only that you try to be consistent in the way you use the numbers."

The subjects assigned positive numbers based on their perception of target motion magnitude produced by the various stimuli. A modulus was not employed. As in the first part of the session, the subjects were exposed to six trains of tone bursts; the ten tone bursts that comprised a train were essentially identical (phase was not controlled).

Experiment I-B

Four Miami University graduate students were paid to complete Experiment I-B. All had participated in previous experiments and were highly practiced on the task.

The subjects were selected because they reported lateral visual shifts in one direction when stimulated in the left ear and shifts in the opposite direction when stimulated in the right ear. Two subjects reported maximum displacements at 500 Hz and the remaining two reported maximum displacements at 1000 Hz. Other acoustical stimulus characteristics were the same as in Experiment I-A.

The subjects completed four trials per day on eight consecutive days. A trial proceeded in the following manner: (a) four tone bursts were delivered to either the right or left ear (pretest); (b) the subject was centrifuged for 2 min at 30 or 60 deg/sec in the clockwise direction; (c) the centrifuge was abruptly stopped; and (d) four tone bursts were immediately presented (posttest). After the tone burst presentation the subject reported the magnitude of visual field shift, as previously, and the direction of the displacement.

The trials were divided into two blocks according to the rotation rate; that is, two trials were completed at one of the rotation rates during which the right (left) and then the left (right) ear was stimulated. After a 15-min rest, two more trials were completed employing the second centrifugation rate. A 5-min rest interval was allowed between trials. Each day the subject received pretest and posttest tone bursts presented to each ear coupled with each centrifugation rate. The order in which the trials were presented was counterbalanced across subjects.

B. EXPERIMENT II--HEAD VIBRATION

Seven Miami University graduate and undergraduate students served as subjects for pay. The subjects met the audiometric criteria employed in Experiment I. All seven subjects were pretested and reported lateral visual field displacements when exposed to acoustical stimuli of 125 dB at either 500 or 1000 Hz.

The apparatus employed for acoustical stimulation and the visual target was the same as previously.

Head vibration was obtained with a Sears Vibrator Massage unit (model 753-2259B). The vibrator exhibited spectral peaks at 120 Hz (reference—0 dB), 60 Hz (-9 dB), 180 Hz (-8 dB), 240 Hz (-9 dB), and 300 Hz (-12 dB). The plastic vibrator tip was held against the subject's right mastoid bone with a force of 300 gr. The force at the subject's skull was determined with a

Grass force/displacement transducer (model FT10), a Grass oscillograph (model 7), and a Tektronik storage oscilloscope (type 564).

The subjects were asked to estimate the magnitude of target motion produced by acoustical transients under each of eight conditions (with or without vibration, left or right ear, 500 or 1000 Hz). The instructions to the subjects were similar to those used in the second part of Experiment I.

Six of the seven subjects completed at least eight experimental sessions and one subject completed six sessions. Each session consisted of eight trials under each of the eight conditions indicated above. A trial consisted of presentation of four tone bursts (repetition rate--0.9/sec, duration--100 msec, onset/offset time--1 msec, intensity--125 dB SPL, frequency--500 or 1000 Hz). At the end of each group of four tone bursts, the subjects estimated the magnitude of visual field displacement. The order of presentation of the eight conditions within a session was counterbalanced within subjects across the eight sessions. At least 2 hr elapsed between sessions.

C. EXPERIMENT III--PRIOR VISUAL FIELD ROTATION

Experiment III-A

Six graduate students who received payment for their participation served as subjects in this experiment. The subjects were selected from a larger group of volunteers by means of a screening procedure. This screening was essentially the same as used in the first part of Experiment I-A except that rotation was not employed. Only subjects who reported visual field displacements to either 500 or 1000 Hz stimuli presented to either the left or the right ear participated in Experiment III. As before, all subjects were audiometrically tested to insure that their hearing did not deviate from audiometric zero by more than 20 dB and were retested after the experiment to ensure that no

permanent damage had occurred.

The acoustical stimulation apparatus was the same as that used in Experiment I. The visual target was also the same with the exception that the viewing distance was 122 cm rather than 150 cm.

Visual field rotation was produced by a drum 92 cm high and 92 cm in diameter. Its interior was lined with white illustration board with black vertical stripes 2 cm wide separated by 5 cm. The subjects' heads were restrained in a U-shaped chin rest with their eyes 33 cm below the top of the drum interior and at a viewing distance of 36 cm from the drum walls. The interior of the drum was illuminated by a 65-W incandescent bulb mounted overhead. For the fixation condition, the subjects fixated upon a 1-cm black paper disk, mounted at eye level 33 cm from the eyes on an L-shaped wire arm extending from the chin rest. For the scanning condition, the subjects tracked four 1-cm copper rivet heads mounted at eye level every 90 deg on the interior surface of the drum.

Those subjects who consistently reported target motion during screening were then assigned to one of two groups: left ear or right ear. Selection was determined by which ear when stimulated produced the most consistent reports of target motion. If no preference existed, subjects were randomly assigned to groups.

The subjects' instructions were essentially the same as those used in the second part of Experiment I.

Each subject participated in 16 sessions held on consecutive weekdays. For each session the subject received two acoustic stimulus trains, a 5-min exposure to the rotating drum, and then two more acoustic stimulus trains. Each stimulus train consisted of 20 tone bursts, initially at an

intensity of 80 dB and rising in steps until reaching 125 dB on the tenth and all succeeding tone bursts. The tone bursts had a duration of 100 msec, an onset/offset time of 1 msec, and an interstimulus interval of 0.9 sec.

During each session each subject received one 1000-Hz stimulus train and one 500-Hz train before drum exposure. Train frequency order was counterbalanced within and across sessions. Subjects were then immediately seated in the drum with their heads in the chin rest. They were then read the following instructions.

> "I would like you to fixate upon the black dot in front of you" (fixation condition) or "without moving your head, follow with your eyes the copper rivets as they pass through your visual field. The drum will spin for 5 min after which I would like you to return to the target viewing chair as quickly as possible. Close your eyes please."

The subjects' eyes remained closed for 15 sec to allow the drum to reach a rotational speed of 12 rpm either toward the ear which received auditory stimulation (homolateral spin) or away from the stimulated ear (contralateral spin). Spin direction was counterbalanced across sessions. After 5 min of drum viewing, the subjects returned to the visual target-viewing chair where they again received auditory stimulus trains of 1000 and 500 Hz and gave magnitude estimates of perceived motion.

<u>Experiment III-B</u>

Four subjects from Experiment III-A participated in Experiment III-B. Experiment III-B was identical in methodology to III-A except on the following points. During drum stimulation subjects always followed the rivets with their eyes and received either homolateral spin or a control condition of no spin. Under the control condition subjects were still required

to close their eyes for 15 sec before drum exposure. Also, in an attempt to equate attentional states, subjects were required to mentally calculate and orally respond to multiplication problems presented auditorily for 60 sec before and after drum exposure. During those calculations the target sheet was covered by a plain sheet of white paper of the same size.

D. EXPERIMENT IV--TARGET ILLUMINATION

A total of 50 students enrolled in introductory psychology courses participated in Experiment IV either to satisfy an experiment participation course requirement or for pay. All subjects received an audiometric examination as in the previous experiments.

Nineteen subjects reported lateral visual field displacements during a screening procedure that was analogous to the first part of Experiment I-A.

The auditory stimulus apparatus and characteristics as well as the visual target were the same as those used in the previous experiments. The visual target was illuminated with the Naren spotlight which was powered through a variac. Light intensity was modified by varying the variac settings. Five light intensity settings (0.8, 2.3, 8.4, 36, and 110 mL at the subject's eye), which were found to produce approximately equal steps of perceived illumination change during preliminary testing, were employed in this experiment.

The subjects were asked to estimate the magnitude of visual field displacement during exposure to acoustical stimulation (10 tone bursts) under each of the five target illumination levels, following instructions analogous to those employed in Experiment I-B. Only one frequency (the one which yielded the most consistent responses during screening) was used. The subjects reported visual displacements of the target at each of the five illumination levels. Order of illumination levels was

randomly varied across subjects.

E. EXPERIMENT V--ALCOHOL INGESTION

Six Miami University students who had participated in an earlier experiment were paid to serve as subjects. All subjects reported target motion upon presentation of acoustical transients. They were given an audiometric examination to ensure that their hearing thresholds did not deviate more than 20 dB from audiometric zero at all frequencies examined. Also, a second audiometric examination was given either immediately or one week following exposure to ensure that their ears had not suffered any permanent damage.

At the onset of the experiment the subjects were weighed to determine alcohol dosage. Weights ranged from 50.9 kg to 103.6 kg. One cc of 100-proof Vodka was given for each kg of body weight. Each alcohol dose was mixed with 480 cc of orange juice.

Subjects were run on four consecutive days. On two of the days subjects received the Vodka-orange juice drink and on the other two they were given plain orange juice. The order in which subjects received the two types of drink was counterbalanced. Three subjects received the alcoholic drink on their first and last session and the other three on their second and third session.

Subjects were tested four times each day. The first test session was performed before ingesting either the alcoholic or nonalcoholic drink. Following this session, the subjects were allowed 30 min to drink either type of beverage and were subsequently tested. Subjects were tested again 30 and 90 min later. Therefore, on each day the subjects were given a pretest and three posttests extended over a two-hr session.

During each testing session, subjects were exposed to four stimulus trains comprised of four tone bursts in each train.

Two tone bursts were delivered to each ear at 500 and 1000 Hz at an intensity of 125 dB. Each testing session began with the tone bursts being presented to the left ear at 500 Hz and 1000 Hz respectively. The subjects assigned positive numbers based on their perception of target motion magnitude. A modulus was not employed.

SECTION III

RESULTS

A. EXPERIMENT I--ANGULAR ACCELERATION

Experiment I-A

No differences between ears in the incidence or magnitude of visual field shifts evoked by acoustical transients were found after $-\alpha_z$ (right yaw) angular acceleration/deceleration. The results that lead to this conclusion are illustrated in Tables 1 and 2 and Fig. 1. Table 1 summarizes the percentage of reports of target motion following rotation at various rates when the acoustical transients were presented to either the left or right ears. No clear pattern emerged from the results for the first part of the experiment. Table 2 presents the magnitude estimation data obtained from the twelve subjects who completed the experiment. The geometric means of the magnitude estimations, calculated across subjects, as a function of ear stimulated and rotation rate are illustrated in Fig. 1. The data from the experiment were analyzed by an analysis of variance (after log or z-score transformation). Two-group differences were evaluated employing the Wilcoxon matched-pairs signed-ranks test. In no case, including the difference between ears following 5 rpm rotation, did the results of the various statistical tests approach significance.

TABLE 1

REPORTS OF TARGET MOTION EVOKED BY ACOUSTICAL TRANSIENTS FOLLOWING ROTATION AT 5, 10, AND 15 rpm (%)

	rpm		
	5	10	15
Left ear	67	83	75
Right ear	67	50	83

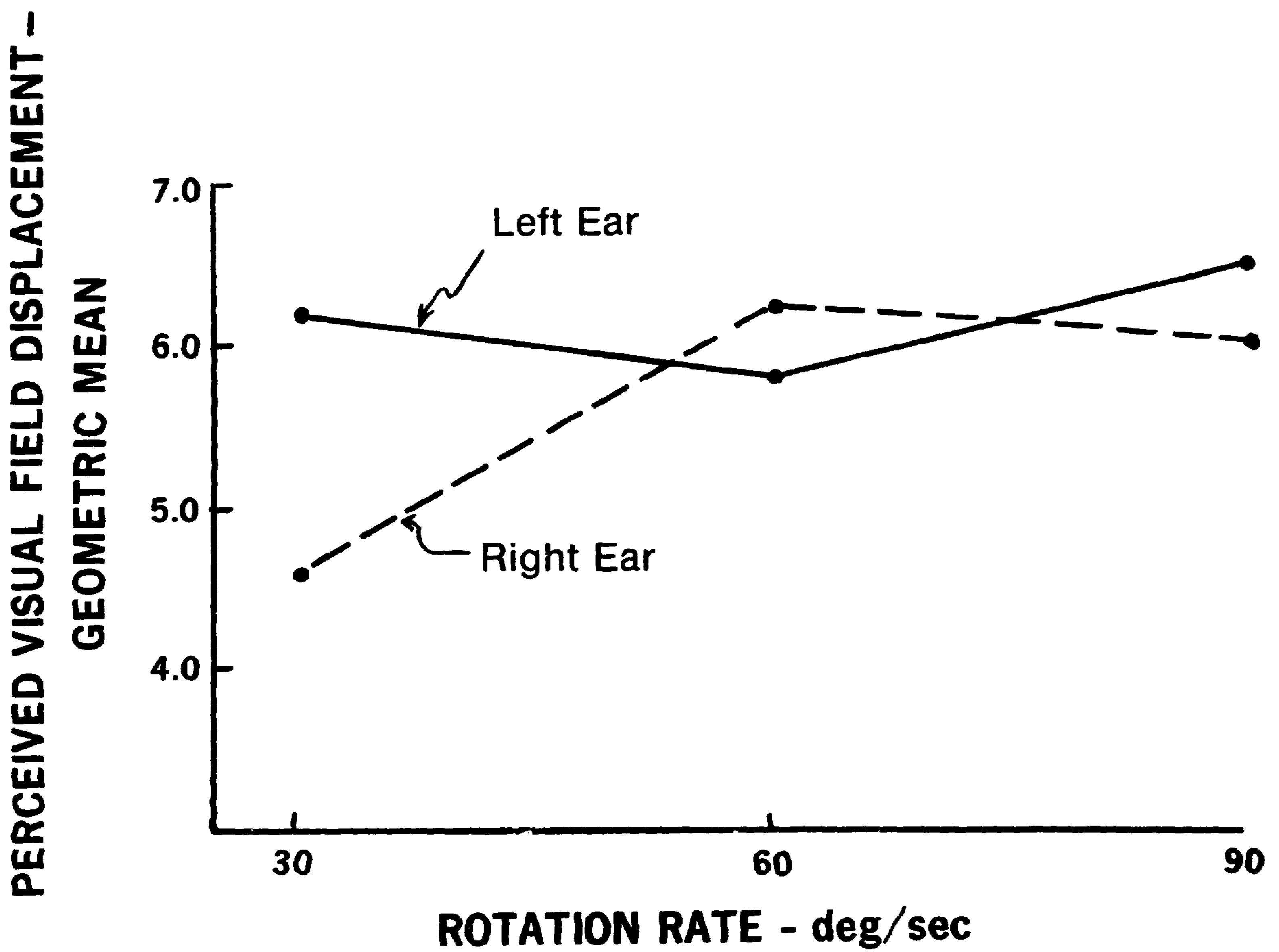


Figure 1. Geometric means of perceived visual field displacements as a function of rotation rate of centrifuge prior to acoustical stimulation. No differences were obtained when the right ear was stimulated versus when the left ear was stimulated.

TABLE 2

MAGNITUDE ESTIMATIONS--EXPERIMENT I-A

Subject	5 rpm Left ear	5 rpm Right ear	10 rpm Left ear	10 rpm Right ear	15 rpm Left ear	15 rpm Right ear
1	0	0	10	10	20	25
2	25	17	20	10	25	10
3	2	2.3	2	3	1.5	3
4	10	3	10	7	5	5
5	2	2	8	1	5	3
6	6	4	4	2	1	4
7	0.5	0	0.5	0	1	0
8	70	20	25	100	10	15
9	1	0	1	3	5	4
10	40	60	10	9	15	10
11	10	15	15	20	5	20
12	3	25	0	1	0.5	0

Experiment I-B

Two subjects reported visual field displacements in the direction of the stimulated ear, and the remaining two subjects reported displacements away from the stimulated ear.

The results from Experiment I-B are illustrated in Fig. 2. The data were normalized within subjects and averaged across subjects. The ordinate of Fig. 2 indicates the average normalized perceived visual field displacement prior to rotation minus the average normalized displacement following rotation. The figure indicates that the reports of visual field displacement were diminished following rotation at 60 deg/sec (relative to 30 deg/sec) when the subjects reported that the pretest acoustical stimulus produced a leftward displacement of the visual field. The opposite pattern of results was obtained when

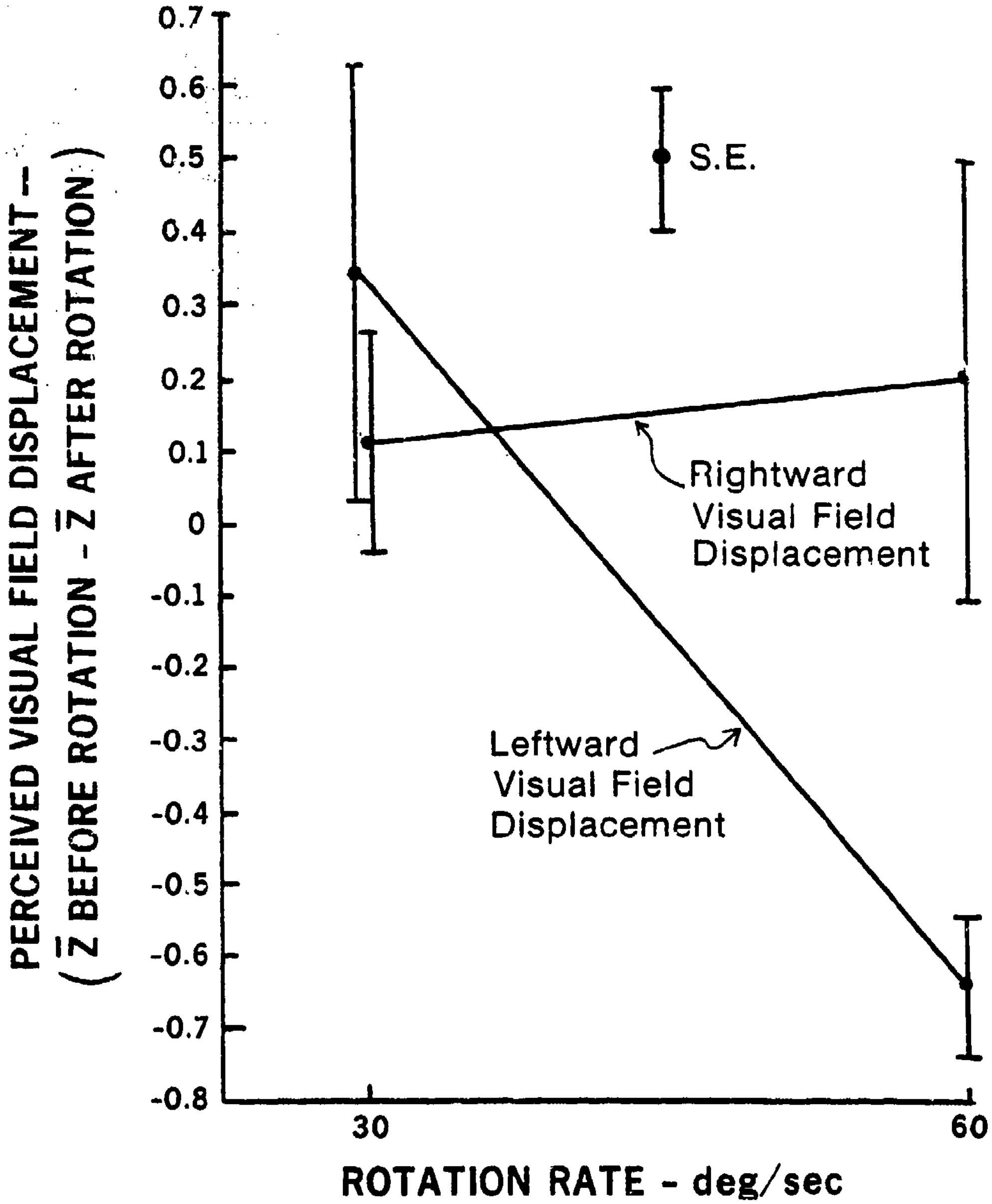


Figure 2. Means of Z-score transformed perceived visual field displacement reports as a function of centrifuge rotation rate. Each data point represents the difference between the reports before and after centrifugation. When the acoustical stimuli produced a leftward visual field shift, centrifugation reduced the apparent visual field displacement; when acoustical stimuli produced a rightward visual field shift, centrifugation enhanced the apparent visual field displacement.

the subjects reported rightward displacement following acoustical stimulation during the pretest.

An analysis of variance calculated from the data illustrated in Fig. 2 yielded an interaction term (rotation rate by direction of displacement during the pretest) which approached significance (F = 3.88; df = 1, 3; p = 0.14). The fact that this F ratio did not reach the normal statistical significance level can be attributed primarily to the limited number of degrees of freedom. If more subjects who exhibited the appropriate pretest pattern of visual field displacements could have been located, we are confident that statistically significant results would have been obtained. However, less than 10 percent of the population appears to exhibit the required response pattern.

B. EXPERIMENT II--HEAD VIBRATION

Subjects reported that the magnitudes of the visual field shifts evoked by the acoustical transients were reduced by nearly 50% when the transients were presented with simultaneous head vibration (see Fig. 3). A three-way analysis of variance calculated from the log-transformed magnitude estimation reports and averaged across subjects indicated a statistically significant difference between the magnitude estimations with the vibration present and the vibration absent (F = 11.94; df = 1, 6; p = 0.01). The interaction between ear stimulated and vibration was not significant (F = 0.06; df = 1, 6; p = 0.82), indicating that the effects of vibration were the same whether the acoustical stimulus was applied to the contralateral (left) or homolateral (right) ear.

C. EXPERIMENT III--PRIOR VISUAL FIELD ROTATION

The results of Experiment III are summarized in Table 3, which contains the geometric means of the magnitude estimation observations. A repeated measure analysis of variance is summarized in Table 4. As indicated in Table 3, the magnitude estimations were lower after exposure to the rotating visual

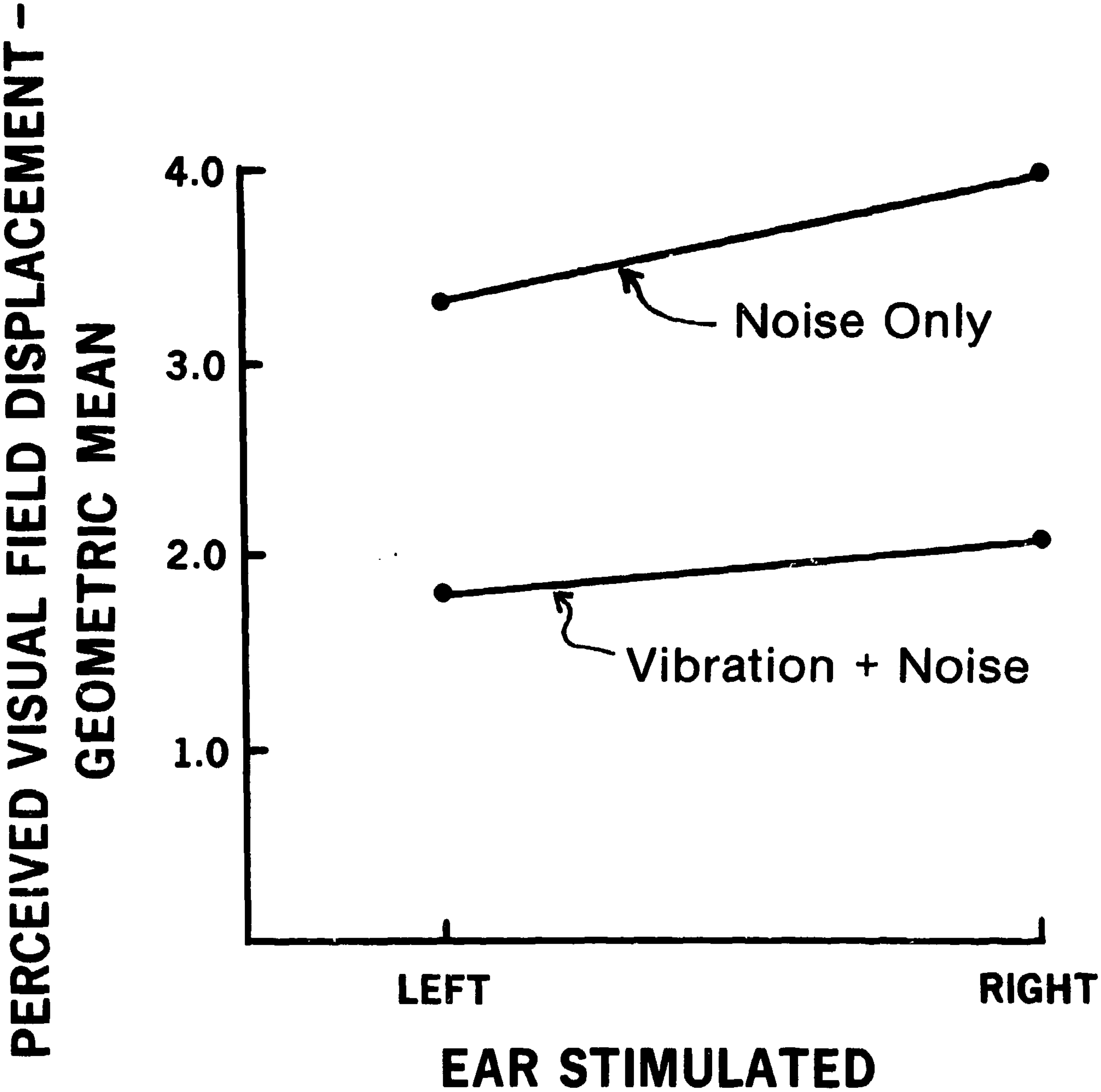


Figure 3. Geometric means of reported visual field displacements as a function of ear stimulated. Simultaneous presentation of vibration and acoustical stimulation reduced the apparent visual field displacement.

field in Experiment III-A; the difference between magnitude estimations before and after drum exposure was significant at the 0.05 probability level (see Table 4). Neither of the other two main effects (drum rotation direction and scan pattern during rotation) reached statistical significance. Analysis of the results from Experiment III-B indicated that neither the magnitude estimation differences before and after drum exposure nor the differences associated with drum rotation (spin vs. no spin) reached statistical significance.

TABLE 3

GEOMETRIC MEANS--EXPERIMENT III

	Experiment III-A			
	Before condition		After condition	
	Homo direction	Contra direction	Homo direction	Contra direction
1000 Hz				
Fix eye movement	5.00	4.47	4.19	2.86
Scan eye movement	3.98	4.15	2.17	2.55
500 Hz				
Fix eye movement	5.71	3.47	3.56	2.89
Scan eye movement	3.54	3.70	1.93	2.88

	Experiment III-B	
	Before condition	After condition
1000 Hz		
Spin stimulation	3.72	2.79
No spin stimulation	3.78	3.85
500 Hz		
Spin stimulation	2.29	2.30
No spin stimulation	3.15	3.47

TABLE 4

REPEATED MEASURES ANALYSES OF VARIANCE FOR EXPERIMENT III

Source	*F*	*df*	*p*
Experiment III-A--1000 Hz data			
Before/after	6.41	1, 5	0.05
Homolateral/contralateral spin	0.03	1, 5	0.87
Fixation/scan	3.46	1, 5	0.12
Experiment III-A--500 Hz data			
Before/after	6.56	1, 5	0.05
Homolateral/contralateral spin	0.03	1, 5	0.86
Fixation/scan	0.97	1, 5	0.37
Experiment III-B--1000 Hz data			
Before/after	0.65	1, 3	0.48
Spin/no spin	0.81	1, 3	0.43
Experiment III-B--500 Hz data			
Before/after	0.36	1, 3	0.59
Spin/no spin	3.08	1, 3	0.18

D. EXPERIMENT IV--TARGET ILLUMINATION

Of the 19 subjects who completed the observations in Experiment IV, five subjects received stimulation at 1000 Hz and 14 subjects were exposed to the acoustical transients at 500 Hz. The magnitude estimation responses from the 19 subjects were combined and the geometric means are presented in Fig. 4. The trend of the data suggests that the higher the level of illumination, the larger the magnitude estimation response; however, the results of a randomized blocks analysis of variance on normalized (within subjects) data failed to provide statistical support for the trend (F = 1.06; df = 4, 68; p = 0.38).

E. EXPERIMENT V--ALCOHOL INGESTION

Alcohol ingestion resulted in diminished magnitude estimation reports. Fig. 5 illustrates that the geometric means for

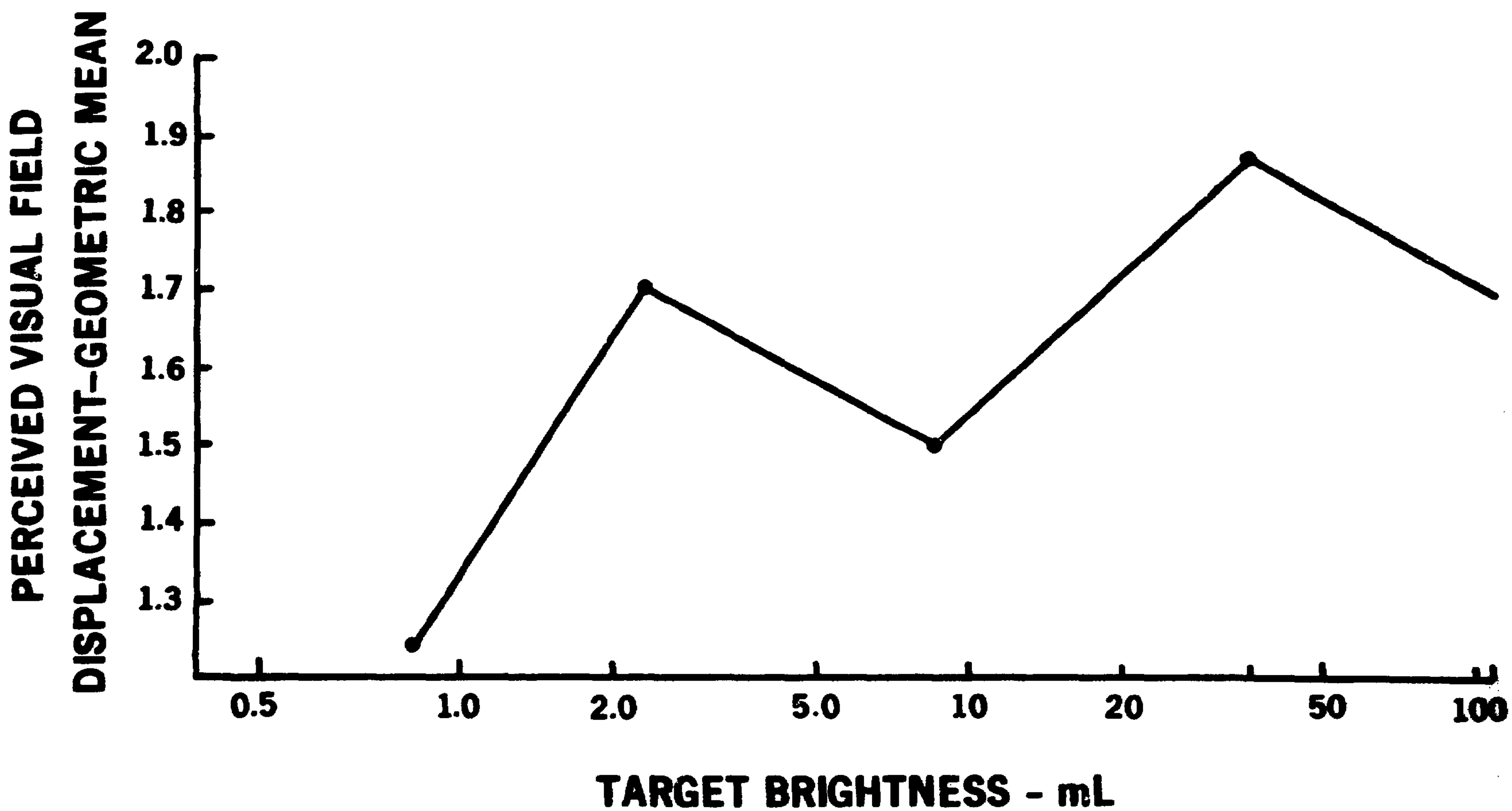
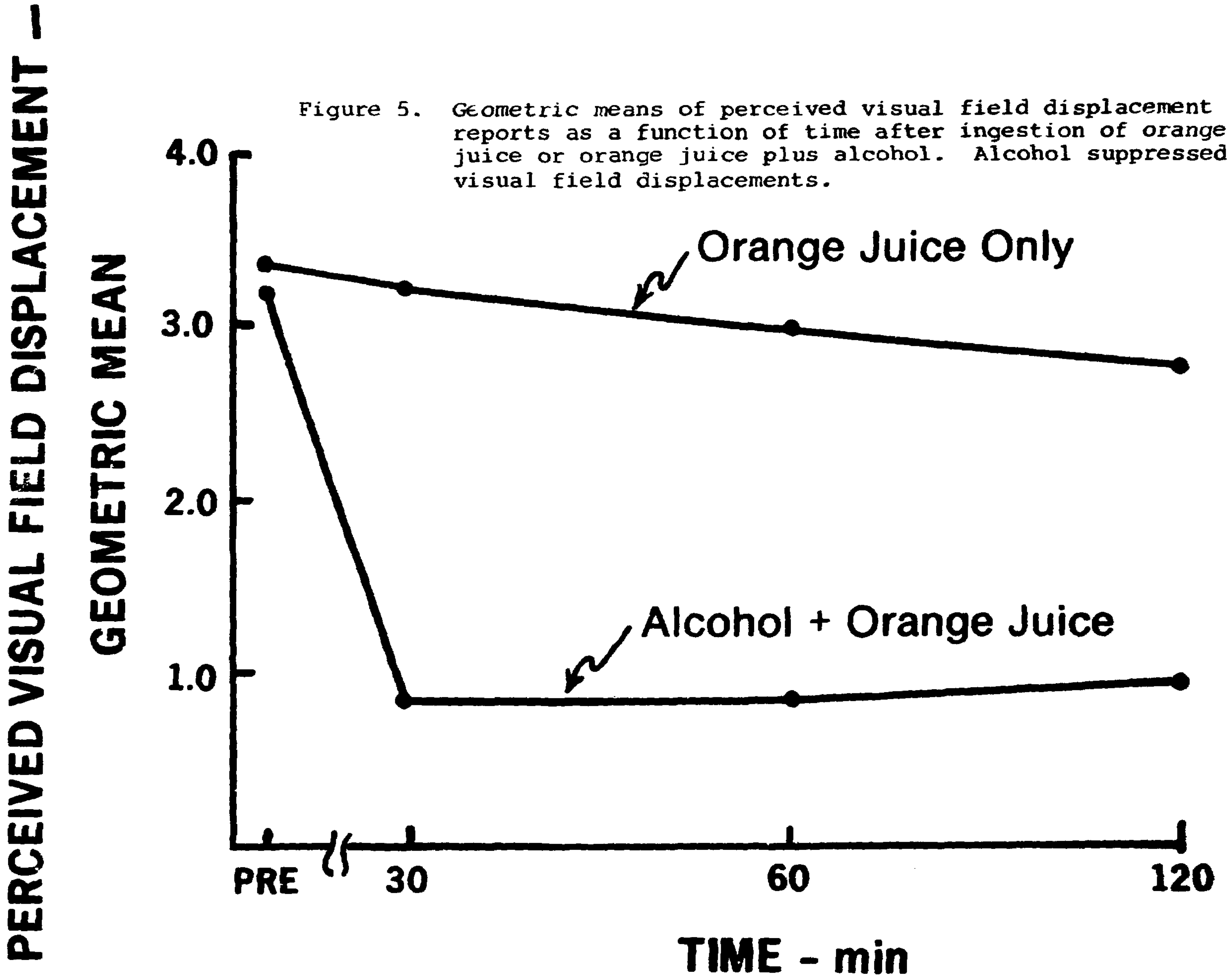


Figure 4. Geometric means of visual field displacement reports as a function of target brightness. The tendency for larger visual field displacements to correlate with target brightness was not statistically significant.

Figure 5. Geometric means of perceived visual field displacement reports as a function of time after ingestion of *orange* juice or orange juice plus alcohol. Alcohol suppressed visual field displacements.



the magnitude estimations following alcohol consumption were approximately one-half as large as those obtained when the subjects drank orange juice alone. The magnitude estimations following alcohol consumption reached a minimum immediately following ingestion and then gradually returned toward the no-alcohol level, whereas magnitude estimations obtained during the no-alcohol tests exhibited a gradual decline across time within a session. An analysis of variance on subject means (collapsed across days, ears, and frequencies) revealed statistically significant effects associated with the presentation of alcohol ($F = 8.68$; $df = 1, 5$; $p < 0.05$), time of observation ($F = 3.61$; $df = 3, 15$; $p < 0.05$), and the interaction between alcohol and time ($F = 7.31$; $df = 3, 15$; $p < 0.05$).

SECTION IV

DISCUSSION

A. EXPERIMENT I--ANGULAR ACCELERATION

The results of Experiment I-A failed to support the hypothesis that the incidence and magnitude of visual field shifts would differ following $-\alpha_z$ angular acceleration/deceleration when the acoustical stimuli were presented to the left or right ear. This result was also contrary to the impressions reported by several subjects who participated in the experiment.

The direction of the visual field displacements reported by the subjects in Experiment I-A differed across subjects. This observation provided an interpretation of the failure to obtain statistically significant results in Experiment I-A and the hypothesis for Experiment I-B. While the angular acceleration stimuli in Experiment I-A may have had strong effects in particular individuals, these effects varied across subjects and disappeared when the group data were evaluated. This variability may be due to the specific pattern of inner ear fluid displacement produced by the acoustical transients in particular individuals. In order to reliably predict the effect of angular acceleration, we would have to know the specific pattern of inner ear displacement produced by the acoustical transients in different persons, as indicated by the direction of perceived cross motion elicited by stimulation of a particular ear.

The observations obtained in Experiment I-B (Fig. 2) support the view that angular deceleration can modify reports of visual field displacements. These observations can be described in terms of the reafference interpretation of the visual field displacement phenomenon described previously (ref. 16). Because the spin table rotated in the counterclockwise direction, the initial direction of angular deceleration-induced eye motion was

toward the subject's left. According to the reafference interpretation, visual field displacement is reported when there is a mismatch between the eye movement expected on the basis of the vestibular signal and the actually received signal concerning the eye movement. To the extent that this mismatch is large, the reported visual field shift would be large. Figure 2 illustrates that the magnitudes of visual field displacement following angular deceleration were reduced when subjects reported leftward visual field displacement prior to rotation. This would be expected from the reafference interpretation because the angular deceleration-induced tendency of the eye to move to the subject's left would reduce the mismatch between the expected and actually received eye movement signals. On the other hand, when the subjects reported a rightward visual field displacement prior to rotation, the angular deceleration resulted in slightly larger reports of visual field displacement. Following the reafference interpretation, the deceleration-induced tendency of the eye to drift toward the subject's left would increase the mismatch between the expected rightward movement from the vestibular receptors and the actually received eye movement signals.

The observation that angular deceleration resulted in alteration of visual field displacement reports supports the hypothesis that the acoustical stimuli acted by displacement of semicircular canal structures.

Following the reafference interpretation, it can be suggested that environmental conditions that enhance visual fixation or that result in a real tendency of the eye to move in a direction opposite to that signaled by the vestibular receptors would enhance reports of sound-evoked visual field displacement.

B. EXPERIMENT II--HEAD VIBRATION

The results of Experiment II indicate that vibration acts to attenuate visual field shifts associated with acoustical

stimulation. The mechanism of this attenuation is probably the middle ear reflex. Informal observations indicate that mastoid vibration elicits a middle ear reflex, which would limit the sound energy entering the labyrinth for a given intensity of sound at the tympanic membrane. This interpretation is supported by the observation that the vibration-induced response reduction was equally effective for the homolateral or contralateral ear because the middle ear reflex is bilateral.

In the introduction it was suggested that vibration might enhance or suppress the sound-evoked visual field displacements depending on whether the vibration was homolateral or contralateral to the sound. Clearly, this suggestion was not supported by Experiment II; rather, the suppression, which was apparently mediated by the middle ear reflex, was sufficient to mask any interaction between the two types of stimulation at the semi-circular canals.

An alternative mechanism for the vibration-induced reduction in the visual displacements reported by the subjects can be proposed. The head vibration may have been sufficient to reduce visual acuity by blurring the image of the target cross on the retina. However, previous research on the effects of vibratory frequencies in the range employed in Experiment II suggests that acuity decrements are negligible (ref 4).

C. EXPERIMENT III--PRIOR VISUAL FIELD EXPOSURE

Experiment III-A resulted in a significant reduction in the magnitude of the visual field shifts evoked by acoustical transients after exposure to the rotating visual field. One interpretation of this result was that visual field rotation exposure produced a central "depression" of visual/vestibular reflexes. Alternatively, the observed differences might have resulted from fatigue, loss of attention, or some other "order effect." In order to evaluate the second interpretation, Experiment III-B was performed. If the depression in magnitude

estimation reports were due to drum rotation, a difference between the spin and no spin groups should have been observed. This was not the case. Further, if the drum exposure produced a decrement in the visual field shift response, a before/after difference should have been observed. The fact that the before/after difference was lost in Experiment III-B suggests that the difference found in Experiment III-A was due to loss of arousal because the major procedural difference between Experiments III-A and III-B was the use of mental arithmetic problems. Mental arithmetic has been used in several previous investigations to maintain eye movement reflexes mediated by the vestibular system and apparently this procedure helps to maintain the amplitude of sound-evoked visual field shifts.

D. EXPERIMENT IV--TARGET ILLUMINATION

The hypothesis that target illumination intensity would be inversely related to visual field shift magnitude was not supported. In view of these results, an alternative proposal can be advanced. This alternative is based on the suggestions advanced previously to account for the failure to correlate eye movements with reports of visual field shift (ref 16). As noted in the discussion of Experiment I-B, it was suggested that the perception of visual field shifts following exposure to acoustical transients resulted from a discrepancy between expected and actually received information regarding changes of stimulation to the retina, following a reafference model. Intense target illumination might serve to increase stability of visual fixation, exacerbating the discrepancy, thus resulting in the perception of increased motion.

E. EXPERIMENT V--ALCOHOL INGESTION

The results of Experiment V support the hypothesis that alcohol ingestion would result in smaller reports of perceived visual field displacements following stimulation with high intensity acoustical transients. At least three interpretations can be advanced to account for the results of Experiment V.

First, the reduction in perceived visual field displacement may reflect a general suppression of the neural pathway between the visual and vestibular systems, as suggested by Schroeder (ref 21). Second, the alcohol may have decreased the precision of the eye position control system. If the eye is spontaneously "wandering" it would be difficult for the subjects to detect sound-evoked visual field shifts. This interpretation is congruent with the difficulties in target fixation reported by the subjects following angular deceleration and noted previously. Third, the alcohol may have impaired the subjects' arousal or attention. The results of Experiment II-B support the view that lowered arousal or attention might be associated with lower reports of sound-evoked visual field displacements.

SECTION V

CONCLUSIONS

Intense acoustical transients evoke reports of visual field displacement in human subjects. The nature of the displacement reported varies across subjects and as a function of stimulus characteristics (particularly intensity and frequency). Experimental manipulations that increase the ability of subjects to maintain visual fixation or that tend to evoke eye movements in a direction opposite to that expected on the basis of the acoustical stimulation increase the magnitudes of the visual field displacements reported. Disruption of the visual fixation mechanism (e.g., by alcohol ingestion) or reduction of the effective acoustical stimulus at the labyrinth by vibration tend to reduce the magnitudes of the visual field displacements reported by the subjects.

REFERENCES

1. Benson, A. J., and Guedry, F. E., "Comparison of Tracking Task Performance and Nystagmus During Sinusoidal Oscillation in Yaw and Pitch," Aerospace Med. 42, 593-601, 1971.

2. Collins, W. E., Gilson, R. D., Schroeder, D. J., and Guedry, F. E., "Effects of Alcohol Ingestion on Tracking Performance During Angular Acceleration," J. Appl. Psychol. 55, 559-563, 1971.

3. Dichgans, J., Held, R., Young, L. R., and Brandt, T., "Moving Visual Scenes Influence Apparent Direction of Gravity," Science 178, 1217-1219, 1972.

4. von Gierke, H. E., and Clarke, N. P., "Effects of Vibration and Buffeting in Man," In Aerospace Medicine, H. Randal (Ed.), Williams and Wilkins Co., Baltimore, 1971.

5. Gilson, R. D., Schroeder, D. J., Collins, W. E., and Guedry, F. E., Jr., "Effects of Different Alcohol Dosages and Display Illumination on Tracking Performance During Vestibular Stimulation," Aerospace Med. 43(6), 656-660, 1972.

6. Gilson, R. D., Guedry, F. E., and Benson, A. J., "Influence of Vestibular Stimulation and Display Luminance on the Performance of a Compensatory Track Task," Aerospace Med. 41, 1231-1237, 1970.

7. Harris, C. S., Effects of Acoustical Stimuli on the Vestibular System, Technical Report 71-58, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, 1971.

8. Harris, C. S., Effects of Increasing Intensity Levels of Intermittent and Continuous 1000 Hz Tones on Human Equilibrium, Technical Report 72-11, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, 1972. [AD 750840]

9. Harris, C. S., and Sommer, H. C., Human Equilibrium During Acoustical Stimulation by Discrete Frequencies, Technical Report 68-7, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, 1968. [AD 675172]

10. Heifer, U., "Oculovestibuläre Reaktion und Blutalkoholkonzentration," Hefte zur Unfallheilkunde 99, 192-197, 1969.

11. Howard, I. P., and Templeton, W. B., Human Spatial Orientation, John Wiley and Sons, London, 1966.

12. Lackner, J. R., and Graybiel, A., "Elicitation of Vestibular Side Effects by Regional Vibration of the Head," Aerospace Med. 45, 1267-1272, 1974.

13. Parker, D. E., and von Gierke, H. E., "Vestibular Nerve Response to Pressure Changes in the External Auditory Meatus of the Guinea Pig," Acta Oto-laryng. 71, 456, 1971.

14. Parker, D. E., von Gierke, H. E., and Reschke, M. F., "Studies of Acoustical Stimulation of the Vestibular System," Aerospace Med. 39, 1321, 1968.

15. Parker, D. E., and Reschke, M. F., "Mechanisms of Acoustical Vestibular Stimulation I. Middle Ear Nonlinearity," Minerva Otorinolaringologica 22, 240-249, 1972.

16. Parker, D. E., Tubbs, R. L., and Littlefield, V. M., "Visual-Field Displacements in Human Beings Evoked by Acoustical Transients," J. Acoust. Soc. Amer. 63, 1912-1918, 1978.

17. Parker, D. E., Tubbs, R. L., Ritz, L. A., and Wood, D. L., Effects of Sound on the Vestibular System, Technical Report 75-89, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, 1976.

18. Reschke, M. F., High-intensity, Audiofrequency Vestibular Stimulation in the Guinea Pig, Unpublished Doctoral Dissertation, Department of Psychology, Miami University, Oxford, Ohio, 1971.

19. Reschke, M. F., Homick, J., Landreth, J., and Parker, D. E., "Acoustical Vestibular Stimulation in Man," Minerva Otorinolaringologica 25, 1975.

20. Reschke, M. F., Parker, D. E., and von Gierke, H. E., "Stimulation of the Vestibular Apparatus in the Guinea Pig by Static Pressure Changes: Head and Eye Movements," J. Acoust. Soc. Amer. 48, 913, 1970.

21. Schroeder, D. J., "Influence of Alcohol on Vestibular Responses to Angular Acceleration," Aerospace Med. 42, 959-970, 1971.

*U.S.Government Printing Office: 1980 — 657-084/444